CLUSTER MICROCLIMATE (LIGHT AND THERMAL) IS A KEY POINT OF GRAPE MATURITY IN MEDITERRANEAN SEMIARID CONDITIONS

LE MICROCLIMAT DE GRAPPES (LUMINEUX ET THERMIQUE) EST UN POINT CLÉ DE LA MATURITÉ DES RAISINS DANS LES CONDITIONS SÉMIARIDES MÉDITERRANÉENNES

Mario DE LA FUENTE[1]*, Rubén LINARES[1], Pedro JUNQUERA[1], Barbara SEBASTIÁN[1], José Ramón LISSARRAGUE[1]

[1] Departamento de Producción Agraria -Viticulture Research Group. Universidad Politécnica de Madrid. E.T.S.I. Agrónomica, Alimentaria y Biosistemas. Ciudad Universitaria s/n. 28040. Madrid, Spain.

**Corresponding author: de la Fuente, M. phone: +33 (0)688409711 or +34645812173, Email: mario.delafuente@upm.es*

Abstract

Sunlight and microclimate inside the clusters zone are key factors in berry development and must composition. In Mediterranean conditions (warm and dry climate), the use of porous systems can help plants establish a better leaf distribution inside the clusters area, providing more space and enhancing certain physiological processes, both in leaves (photosynthesis, ventilation, transpiration) and berries (growth and maturation). Berry temperature can vary between 2-10ºC or even more in inner clusters, depending on their exposure (Spayd *et al*., 2002). Dynamics of light and thermal cluster microclimate: yield and must composition at maturity stage have been studied in three different systems: sprawl system with 12 shoots·m^{-1} (S1); sprawl system with 18 shoots·m^{-1} (S2) and vertical positioned system or VSP with 12 shoots m^{-1} (VSP1). The main objective of this study was to show the differences among the three training systems in terms of cluster exposure at the maturity stage and to quantify these effects on berry and must composition. Results showed that vertical system (VSP1) obtained more percentage of cluster exposure at midday and midafternoon (+24%) comparing to non-positioned and free systems (S1 and S2). The cluster light microclimate of VSP1 showed a higher percentage of interception of photosynthetically active radiation (12-32% PAR), while S1 and S2 kept lower values (3-25%), during the day. Small differences (1-2ºC) were obtained inside the clusters depending on the training system and crop load, but time and percentage of cluster exposures were relevant too, especially in warm and dry climates where the average daily temperature at maturing is high (maximum temperature: Tx 33.5 ºC; mean temperature: Tm 25.6 ºC). Both effects of sprawl treatments (crop load and training system) resulted in better plant microclimate for trial conditions, mainly improving the exposure of internal clusters and internal canopy ventilation, minimizing the over exposure of external clusters (≤24%). Finally, berry and must composition did not change (Brix, pH and total acidity) much, while the composition of anthocyanins improved with low exposure and non-positioned systems (S1 and S2). Higher crop load treatment (S2) showed an evident increase in yield (16%) at harvest.

Keywords : sprawl, training system, cluster microclimate, canopy, grape composition.

Résumé

L'ensoleillement et le microclimat au sein des zones de grappes sont des facteurs clés pour le développement des baies et pour la composition du moût. Dans des conditions méditerranéennes (climat chaud et sec), l'usage de systèmes poreux peuvent aider les plantes à constituer une meilleure répartition des feuilles au sein des grappes, laissant plus de place et améliorant certains processus physiologiques, à la fois au niveau des feuilles (photosynthèse, aération et transpiration) et des baies (croissance et maturation). La température des baies peut varier entre 2-10°C voire plus dans la partie intérieure des grappes selon leur degré d'exposition (Spayd *et al.,* 2002). La dynamique de la lumière et le microclimat thermal au sein des grappes : le rendement et la composition du moût à maturité ont été étudiés dans trois systèmes différents : « sprawl » système avec 12 rameaux m^{-1} (S1) ; « sprawl » système avec 18 rameaux m^{-1} (S2) et système de positionnement vertical ou « VSP » système avec 12 rameaux m^{-1} (VSP1). Le principal objectif de cette étude était de montrer les différences entre les trois systèmes de conduite en terme d'exposition de la grappe à maturité ainsi que de quantifier leurs effets sur la composition des baies et du moût. Les résultats ont montré que le système vertical (VSP1) permet d'obtenir un pourcentage plus élevé de grappes exposées à la lumière à mi-journée et au milieu de l'après-midi (+24%) comparé aux systèmes libres non positionnés (S1 et S2). Le microclimat et l'exposition des grappes de VSP1 ont permis d'obtenir un pourcentage plus élevé d'interception des radiations activées par photosynthèse (12-32% PAR), alors que S1 et S2 n'ont permis d'obtenir que des valeurs plus basses pendant la journée (3-25%). De faibles différences (1-2°C) furent notées au sein des grappes selon le système de formation et la charge, mais le temps et le pourcentage d'exposition des grappes furent pertinents également, notamment compte tenu du climat chaud et sec où la température journalière moyenne à maturité est élevée (température maximale : Tx 33.5 ºC; température moyenne ; Tm 25.6 ºC). Les deux effets des « sprawl » systèmes (système de conduite et charge), ont permis de créer de meilleurs microclimats de plantes pour des conditions d'essai, améliorant grandement l'exposition de l'intérieur des grappes et l'aération interne des canopées, minimisant la sur exposition de la partie extérieure des grappes. Enfin, la composition des baies et du moût n'a pas beaucoup changé (Brix, pH et acidité totale), en revanche la composition des anthocyanes s'est améliorée grâce à une faible exposition et aux systèmes non positionnés (1 et S2). Un traitement par des charges plus élevées (S2) a montré une augmentation significative du rendement (16%) lors des vendanges.

Mots-clés : système non positionné, système de conduite, canopée, microclimat de grappes, composition de raisins

1. Introduction

Several authors have showed (Schultz 1995; Mabrouk, *et al*. 1997; Gladstone and Dokoozlian, 2003) a real improvement of yield and berry quality with an adequate canopy management. An adequate leaf exposure porosity and canopy density, as well as a certain degree shading in clusters area (a key factor during the ripening), can help obtaining the objectives chosen by the vineyard and cellar managers (de la Fuente *et al.,* 2013). The plant geometry and training system should be accompanied by a proper sunlight and temperature microclimate in the clusters area and in the rest of the plant (Spayd, *et al*. 2002).

At harvest, the value of incident photosynthetic active radiation (PAR) inside the canopy is usually low (about 10% of total ambient radiation). However, in warm climates diffuse radiation is relevant too, where its value is normally higher than in cool climates. Canopy management can modulate the amount of the diffuse radiation inside cluster area instead of incident PAR, which can be increased by time exposure and temperature (Berqvist *et al.,* 2001). Total exposure can produce worse effects on yield and berry composition: degradation of organic acids, polyphenols and anthocyanins compounds (Spayd, *et al*. 2002), or decoupling of these components according to sugar content (Sadras *et al.,* 2013). Grapes exposed to direct radiation are more sensitive to over ripening and they can even suffer a dehydration process in the Mediterranean regions, when the temperature during the ripening after midday is frequently between 30-35 ºC or higher (40ºC).

In warm and dry climates, the use of porous systems is required in order to allow a better leaf distribution inside the plant, causing more space in the clusters area and modulating the sun exposure of the bunches. Sunlight, air ventilation within canopy, temperature cluster and microclimate are affected by the exposure and radiation percentage received during growth and maturation period; this is the main factor to getting an optimum bunch microclimate, which can reduce the heterogeneity in berry maturity process (Deloire and Hunter 2005). Therefore, the key point for a well microclimate management inside the canopy is heat flux control, which is usually generated by three factors: surface area exposed (SA) to PAR (direct or indirect) radiation; intensity or thermal value (related to the temperature) and time of exposure (de la Fuente, 2009). Likewise, there are many other factors with important effects on plant microclimate, which are related to training system. That is the reason for comparing different training systems in this study. Sprawl is a porous training system with alternating spur-pruned uniform distribution along horizontal cordon that caused spacing clusters zone. VSP, on the other hand, is a vertical, rigid positioning system whose shoots and leaf area caused a linear clusters zone, usually closely spaced.

2. Material and Methods

This field experiment was conducted over two consecutive seasons (2006 and 2007) in an experimental trial in Toledo (Spain), on a fine clay-sandy soil (Palexeralf, Soil Survey Staff, 2003) with a 50 cm depth clay superficial horizon (50-55% of clay). The weather conditions were typical for Mediterranean semiarid climate (Papadakis, 1966). The cultivar was Syrah, grafted on 110R and spaced 1.2 m, in the NW-SE (+8.3º to West) orientated rows with 2.7 m between rows. Irrigation system drippers ($3 \cdot l\ h^{-1}$) were spaced 1.2 m along the planting line and the amount applied was equal for all treatments. Climatic conditions of 2006 and 2007 were significantly different being 2006 campaign extremely warm while 2007 did not. Differences can be observed mainly in accumulated growing degree days (2000 *vs*. 2525 GDD), rainfall (168 *vs*. 246 mm) and in evapotranspiration reference (1211.1 *vs*. 1064.6 mm; Eto) index too. Trial was designed with three treatments placed into four blocks at random and each experimental plot consisted of 20 control plants, separated by rows and vines edge. The three examined treatments, in order to assess the impact of training system and crop load, were: i) VSP1, *Espaldera* or vertical positioned system (VSP) with 12 shoots/m of crop load, ii) S1, Sprawl with 12 shoots/m of crop load and iii) S2, Sprawl with 18 shoots/m of crop load. (50% crop load more than VSP1 and S1).Vines were spur pruned and trained in a bilateral cordon at the height of 1.40 m. The sprawl system had a single couple vegetation wires from 0.4 m to the basal wire and they opened 0.6 m between wires. VSP system had a couple wires from 0.3 m to the basal wire and a higher wire at 1.5 m to basal wire.

Light microclimate measures were taken on six vines (three per line side), in two blocks per treatment, in the same order (vines and blocks) for each measurement. A linear PAR sensor (LI-191SA, LICOR®) and data logger (LI-1000, LICOR®) were used to obtain experimental data. A sensor was placed in plant line at the cluster area to record the incident radiation values supported by bunches just at that moment. A simplified balance (Sánchez de Miguel *et al*., 2010) was calculated through the percentage or difference between incident radiation (Ri) and radiation in cluster area (Rtb). At the same time, thermal microclimate was calculated by sampling in 15 randomized bunches per two blocks per treatment. It should be noted that in 2007, the degree of sun exposure for each bunch was pointed all the time (as in 0= non-exposed and 1= sun exposed, respectively). Infrared thermometric sensor (model FX-410, Flashpoint®) was used in constant sweep measures mode under its technical characteristics: accurate to ±0.5-1% or ºC and estimated time measure 0.2 s. Light and thermal measures were taken at ripening at different hours (8, 12 and 16 s.t.) during a clear day for both consecutive seasons (2006 and 2007).

A reproductive yield study was done during the harvest (30/08/2006 and 05/09/2007) on ten previously selected plants for each treatment and block. Cluster number, average cluster weight, average berry weight and berry number per cluster and yield (kg m^{-1}) were calculated and counted, and each cluster individually hand-harvested from each plant. A digital field balance (Jadever® JCA series; maximum capacity 60 kg; accurate to 1 g) was used for experimental data measurements. In addition, during the harvest a 100-berry sample per single plot was collected to follow 100-berries weight (g), SST (ºBrix), pH and phenol maturity, according to Glories (2001) method, so the final values corresponded to harvest date of each year.

3. Results and discussion

Light microclimate

Geometry of the training system improves the incident radiation in the cluster area, as long as the same parameters of its training system (e.g. distance between rows) remain fixed. In both years (Table 1), results measured at 8, 12 and 16 s.t. reflect a greater exposure (during all day) of treatment VSP1, reaching higher values compared to S2 (the increase between 6-22%) or S1 (the increase between 1-18%).

Table 1. *Light microclimate bunches measures for three treatments at maturity.*
Microclimat lumineux de grappes données pour les trois traitements à la maturation.

Year	Treatment	PAR Percentage (%) at cluster area (Rtb) (μmol · m^{-2} ·s^{-1})		
		8 s.t.	**12 s.t.**	**16 s.t.**
2006	VSP1	32.13 a	14.16	27.94 a
	S1	14.43 ab	14.36	23.60 ab
	S2	10.98 b	15.50	21.95 b
	EEM[1] (n1=12)	5.61	3.55	5.90
	Sig[2]	***	NS	*
2007	VSP1	12.53	18.80 a	27.09 a
	S1	8.64	16.35a	25.81 a
	S2	3.56	7.45 b	14.58 b
	EEM[1] (n2=8)	2.96	3.78	5.55
	Sig[2]	NS	*	*

Year	Treatment	Bunches Sun Exposed Percentage (%)		
		8 s.t.	**12 s.t.**	**16 s.t.**
2007	VSP1	33.33	41.67	51.67 a
	S1	40.00	30.00	38.33 ab
	S2	35.00	26.67	28.33 b
	EEM[1] (n1=12)	5.59	5.59	6.58
	Sig[2]	NS	NS	*

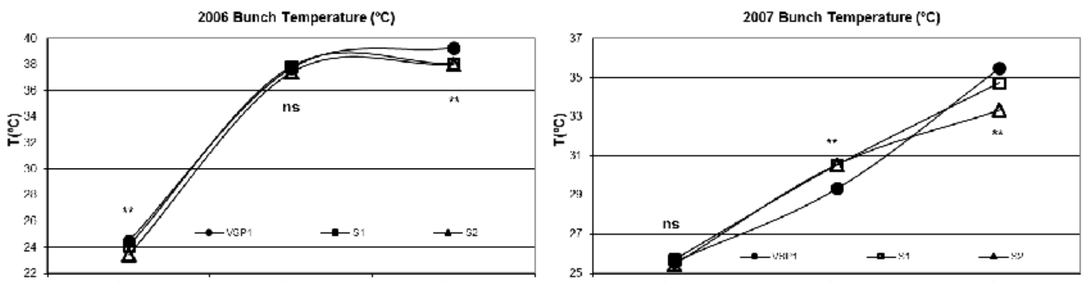
[1] EEM: standard average error for n= 12 and 8 samples per 2006 and 2007 respectively.
[2] Sig: significant differences; ns, *, ** and *** means that there are no significant differences; P<0.05, P<0.01 and P<0.001 respectively. The values with the same letter are equal (T. Duncan). P-values were determined by analysis of variance.

At midday (12 s.t.), sprawl systems cause a higher overhead opening which produces lower values for percentage of PAR intercepted at cluster area (0-10%, for 2006 and 2007 respectively). According to other authors (Maigre, 2000; Dokoozlian and Kliewer, 1995), differences in the morning could decrease the efficiency of photosynthesis process, but differences after midday (usually higher, near to 25% PAR) can produce negative effects on physiological process of the plant. After midday (16 s.t.), results show that sprawl systems scored between 1-13% less percentage of PAR radiation than VSP1 system. Increasing load inside the same system can produce mitigation of sun exposure between 2-10%. S2 scored less PAR percentage than S1 for all measures in both years. These differences are very interesting in warm climates, where one of the main goals is not to cause leaf and clusters overexposure in order to prevent premature senescence and berry over ripening process (de la Fuente *et al.*, 2013). It seems to be clear that a combined effect between crop load and training system may mitigate light over exposure, and avoid undesirable over ripening berry effects.

Thermal microclimate

The results of thermal microclimate (Table 2) show that VSP1 obtained higher temperature values in the morning (≤1ºC at 8 s.t. in 2006) than sprawl systems or the same values (2007) according to others authors (Baeza, 1994).

Table 2. *Thermal microclimate bunches measures for three treatments at maturity[1].*
Microclimat thermique des grappes données pour les trois traitements à la maturation[1].



[1] Sig: significant differences; ns and ** means that there are no significant differences and P<0.01 respectively. The values with the same letter are equal (T. Tukey). P-values were determined by analysis of variance.

At midday, there were not differences or were irrelevant (e.g. ≤1ºC at 12 s.t. in 2007) among treatments because the effect of higher overhead opening of sprawl systems is less relevant than the perpendicular sun position related to the row orientation at this hour. In Mediterranean conditions, hydric daily deficiency produces stomata's closure at midday and during the first afternoon hours, which means that frequently, there are no temperature differences among treatments.

In warm climates, the temperature goes on during the whole afternoon, and several processes of dehydration and over ripening can occur inside the canopy, affecting the bunch area and the leaves. S2 had less temperature (1-2 ºC for both years) than S1 and VSP1 at 16 s.t. Several authors have found similar gaps in thermal microclimate of bunches, close to 1-4ºC (Maigre, 2000; Bergqvist *et al.*, 2001; Spayd *et al.*, 2002; Tomasi *et al.*, 2005). It should be noted that temperature could arise to 35-40ºC during the afternoon, being small differences more relevant as a limiting factor for physiological process at this time of the day due to excessive heat. Even though this thermal ratio was not excessive, the amount of bunches exposed in the afternoon is a key factor, too.

The data show (Table 1) that there were no significant differences in the morning, but after midday, the percentage of sunny bunches (this referring to the total of the clusters randomly sampled) was higher in VSP1 comparing to S1 (+14%) or S2 (+24%). It means that VSP1 show more than 50% of its bunches at this time, while S1 and S2 don't reach 30%.

Finally, with an non-positioned free exposure system, the plant shows a higher overhead opening and exposes less number of bunches to solar direct radiation, or during less time (because flow radiation unit per berry is smaller), so dehydration and over ripening process is not caused easily.

Yield components, berry sampling and juice analysis

During 2006 and 2007 the main crop load effect was showed (Table 3), where higher load treatment (S2) had yield increment of 16% in comparison with the others treatments. On the other hand, S2 showed lower average bunch weight (from 17.0 to 22.5%) and reduced number of berries (from 12 to 21%) per cluster, but it was balanced by higher cluster number per vine (from 32 to 35%). Even in 2007, S2 had the same average berry weight (only in 2006 it was lower, between 4.4 to 9.2%), caused by a higher crop load. Therefore, with an increment of load the berry size will decrease, but the number of berries will increase, which has direct effect on total yield and, at same time, an increase in skin/flesh ratio during harvest. Leaves and cluster microclimate are the key factors (Vanden Heuvel *et al.* 2004) for determining the acidity content, pH and K of must and consequently, wine composition. The differences obtained during 2007 for acidity and pH values are not quantitatively significant (8-7%) and are probably due to a better exposure to radiation clusters, which increases final pH (Bergqvist *et al.* 2001 and Spayd *et al.* 2002).

Table 3. *Yield partitioning and must composition in 2006 and 2007 growing seasons for three treatments at harvest. Composantes du rendement et moût en 2006 et 2007 pour les trois traitements à la récolte.*

Treatment	Yield partitioning 2006					Yield partitioning 2007				
	Nº Clusters·m^{-1}	Yield (Kg·m^{-2})	Cluster average weight (g)	100 Berries average weight (g)	Nº berries·cluster^{-1}	Nº Clusters·m^{-1}	Yield (Kg·m^{-2})	Cluster average weight (g)	100 Berries average weight (g)	Nº berries·cluster^{-1}
VSP1	24.68 b	1.73 b	190.42 a	111.34 a	171.19 a	20.96 b	1.61 b	204.36 a	150.54 b	135.63 a
S1	23.82 b	1.71 b	195.10 a	104.57 b	187.34 a	21.04 b	1.61 b	206.55 a	160.09 a	128.29 a
S2	36.20 a	2.05 a	153.24 b	101.05 c	152.06 b	30.66 a	1.93 a	169.32 b	158.7 a	106.92 b
EEM[1] (n=40)	0.604	0.041	6.09	0.081	1.02	0.46	0.10	7.71	1.39	5.05
Sig[2]	**	**	**	**	**	***	***	**	***	***

Treatment	Must Composition 2006					Must Composition 2007				
	ºBrix	pH	IPT	Antocian extractables (mg·L^{-1})	Total Antocian content (mg·L^{-1})	ºBrix	pH	IPT	Antocian extractables (mg·L^{-1})	Total Antocian content (mg·L^{-1})
VSP1	25.1	3.5	46.7	794.33	1470.35 b	25.2	3.06 b	45.8	931.0	1172.5
S1	25.9	3.5	54.7	936.95	1804.34 a	25.4	3.13 a	51.8	976.5	1228.5
S2	25.8	3.5	52.7	983.94	1903.30 a	24.7	3.20 a	47.7	861.0	1197.88
EEM[1] (n=8)	0.76	0.02	2.54	76.94	81.28	0.27	0.02	4.1	102.7	57.1
Sig[2]	ns	ns	ns	ns	*	ns	**	ns	ns	ns

[1] EEM: standard average error for n= 40 and 8 samples per yield and must composition respectively.

[2] Sig: significant differences; ns, *, ** and *** means that there are no significant differences; P<0.05, P<0.01 and P<0.001 respectively. The values with the same letter are equal (T. Duncan). P-values were determined by analysis of variance.

The differences obtained during 2007 for acidity and pH values are not quantitatively significant (8-7%) and are probably due to a better exposure to radiation clusters, which increases final pH (Bergqvist *et al.* 2001 and Spayd *et al.* 2002). Data from total and extractable anthocyanin content (Table 2) reflect the effect of increasing shading clusters area in the final berry synthesis of anthocyanins, which is very useful in winemaking process (Haselgrove *et al.* 2000). It should be noted that cv. Syrah is very sensitive to the changes in thermal effects during total anthocyanins synthesis (Spayd *et al.* 2002). This effect causes differences in berry anthocyanins content, which are heavier in extremely hot conditions (2006), reaching around 20% in open and non-positioned free systems. Finally, crop load does not change must composition notably, but it increase total plant yield because it provides more clusters. These are less exposed to sunlight, and with this training system, the degradation of anthocyanins at the end of ripening can be prevented. The effect of the load is less important than the use of open training system, which modify light and thermal microclimate through spatial distribution of vegetation and shading effects in the plant, increasing phenolic and anthocyanic berry content.

4. Conclusion

Double effect due to non-positioned open system (sprawl) and crop load increment may mitigate the light over exposure (± 10%), causing differences in thermal microclimate (± 1-2ºC). Even if these differences are not excessive sprawl systems show a higher overhead opening, and expose either less number of bunches to solar direct radiation (≤ 24%) or during less time after midday, avoiding undesirable over ripening and dehydration berry effects. Free and non-positioned systems can help improving not only the plant microclimate, but also anthocyanic berry composition without any other relevant change in must composition, allowing yield increase (if there is enough water available in plant-soil system). Finally, the results show that sprawl treatments (crop load and training system) resulted in better plant microclimate for these trial conditions, mainly improving the exposure of internal clusters and internal canopy ventilation, minimizing so the over exposure of external clusters, and causing some benefits to yield and berry composition.

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Literature cited

BAEZA P. 1994. Caracterización ecofisiológica y evaluación agronómica de diferentes sistemas de conducción del viñedo (*Vitis vinifera L.*) en regadío**.** Tesis doctoral.. Producción vegetal: Fitotecnia. E.T.S.I.A. U.P.M. Madrid. 209 p**.**

BERGQVIST J., DOKOOZLIAN N., EBUSIDA N., 2001. Sunlight exposure temperature effects on berry growth and compositon of Cabernet-Sauvignon and Grenache in the Central San Joaquin Valley of California. Am.J.Enol. Vitic. 52(1), 1-7.

DE LA FUENTE M. 2009. Caracterización geométrica, ecofisiológica y evaluación agronómica de sistemas continuos de vegetación libre (SPRAWL) vs. espaldera para atenuar la sobreexposición de hojas de racimos en cv. syrah (*Vitis vinifera L.*) en viñedos de zonas cálidas. Tesis doctoral. E.T.S.I.A. Producción Vegetal: Fitotecnia. Madrid. Universidad Politécnica de Madrid. 301 p.

DE LA FUENTE M., LINARES R., BAEZA P., LISSARRAGUE J.R., 2013. Importance of canopy porosity into vineyard and the relationship with the grape maturity. Digital estimation method. Ciência e Técnica Vitivinícola 28 and Proc. of 18th International GiESCO Symposium, 2013. Universidade do Porto (Portugal) 633-638p.

DELOIRE A., HUNTER J.J., 2005**.** Microclimat des grappes et maturation du raisin. Le Progrès Agricole et Viticole. 122. 151-157.

DOKOOZLIAN N., KLIEWER W. M. 1995. The light environment within grapevine canopies. Am.J.Enol. Vitic. 46(2), 209-226.

GLADSTONE E. A., DOKOOZLIAN N. 2003**.** Influence of leaf area density and trellis/training system on the light microclimate within grapevine canopies. Vitis 42(3), 123-131**.**

HASELGROVE L., BOTTINF D., HEESWIJCK R., ROD P.B., DRY P., FORD C., ILLAND P.G. 2000. Canopy microclimate and berry composition: the effect of bunch exposure on the phenolic composition od Vitis vinifera L. cv Shiraz grape berries. Aus. J. Grape and Wine Research 6: 141-149.

SPAYD S., TARARA J., MEE D.L., FERGURSON J.C. 2002. Separation of sunlight and temperature effects on the composition of Vitis vinifera cv. Merlot berries. American Journal of Enology and Viticulture 53(3), 171-182.

SCHULTZ H. R. 1995**.** Grape canopy structure, light microclimate and photosynthesis I. A two dimensional model of the spatial distribution of surface area densities and leaf ages in two canopy systems. Vitis 34(4), 211-215**.**

MAIGRE D. 2000. Essai d´enherbement et de fumure azotée sur Gamay dans le bassin lémanique. 3. Comportement physiologique et microclimat des grappes. Revue Suisse de Vitic. Arboric. Hortic. 32, 335-339.

MABROUK H., SINOQUET H., CARBONNEAU A. 1997. Canopy structure and radiation regime in grapevine II: Modelling radiation interception and distribution inside the canopy. Vitis 36(3), 125-132.

SADRAS V.O., MORAN M.A., BONADA M. 2013. Effects of elevated temperature in grapevine. I berry sensory traits. Australian journal of grape and wine research 19, 95-106.

SANCHEZ DE MIGUEL P., JUNQUERA P., BAEZA P., LISSARRAGUE J.R. 2010. Balance of photosynthetic active radiations in vineyard: method and applications. Le progrès agricole et viticole, 127 (23-24), 461-465.

SMART, R. E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. A review. Am.J.Enol. Vitic. 36(3), 230-239.

SPAYD S.E., TARARA J.M., MEE D.L., FERGUSON J.C. 2002. Separation of sunlight and temperature effects on the composition of Vitis vinifera cv. Merlot berries. American Journal of Enology and Viticulture (53). 171-182.

TOMASI D.; PASCARELLA, G.; SIVILOTTI, P.; BELVINI, P. 2005. Canopy geometry modification and grapevine performances as affected by training system.In: C.R. XIV GESCO. Vol. 2. Greisenheim- Allemagne. pp. 351-357.

VANDEN HEUVEL J. E., PROCTOR J. T. A., SULLIVAN J.A., FISHER K.H. 2004. Influence of training/trellising system and rootstock selection on productivity and fruit composition of Chardonnay and Cabernet franc grapevines in Ontario, Canada. Am. J. Enol. Vitic 55(3): 253-264.